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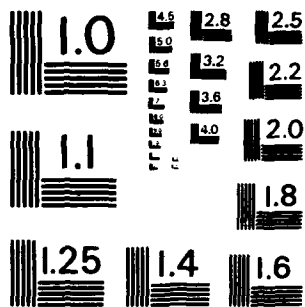
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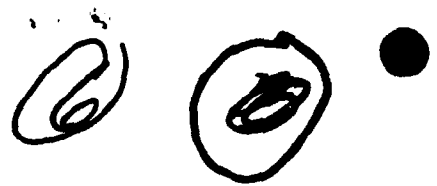
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Research Project: CREEP AND SLIDING IN CLAY SLOPES:
MUTUAL EFFECTS OF INTERLAYER
SWELLING AND ICE JACKING

Principal Investigator: KURT A. CZURDA

Contractor: UNIVERSITY OF INNSBRUCK

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In swelling clays the frost heave results not only from ice lense formation but includes swell heave as well. During the growth of the lonses the clay desiccates gradually and promotes further water ad- sorption through the unfrozen hygroscopic water layers. This forces the clay phases to expand and the excess water to form ice lenses, finally resulting in a maximum heave, composed of a freeze and a clay swell part.		

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Measurements of the volumetric expansion of clays subjected to freezing temperatures show that the amount of volume increase is greater than the expected 10-11% increase in pore volume due to the freezing of the water in the soil. The increase in volume is the result not only of frost heave, as well tested and calculated phenomenon, but also of water uptake around clay flakes and within their crystal interlayer spaces. Therefore heave calculations in case of swelling clay soils have to consider swell heave in addition to pure frost heave. On thawing, swelling clays not only rearrange their microfabric but remain expanded for a much longer time than coarser grained soils or clays without swelling phases.

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1. Objectives of Research Project

Creep in clay slopes, a very slow but steady movement, as well as sliding, a more rapid en bloc movement, has to have a "trigger" and in addition "preparing causes" by modification of the internal environment.

Swelling and shrinkage behaviour of special - but very common - layer silicates and forming of ice lenses in scales between interlayer dimensions and visible ice layers might belong to the preparing causes.

What happens during frost periods when water is bound by ice lenses and probably cannot act as swelling agent? Are there mutual effects when ice melts and water now is available for uptake into the space of clay minerals? Distinct, measurable volume changes take place in terms of shrinkage as well as swelling. Furthermore: a leaching process starts, which probably accumulates or carries off different ions. Mineralogical, chemical and microfabric changes take place. This must be an important preparing process in creep or sliding movements of clay slopes!

The methods in overcoming the phenomena involve site investigation and laboratory testing programmes. Site investigation on moving clay slopes or in danger of moving within the alpine Molasse formation comprises drilling, penetration testing, piezometer and hydraulic flow- and soil strain measurements - as well as ground temperature registrations. Laboratory testing programmes have to start with identification of the material by petrographic and bulk chemical analyses. Interlayer cations have to be traced and leaching processes simulated. Swelling and shrinkage by moisture uptake and during frost-thaw cycles will be measured according to different structural directions in a dilatometric apparatus.

Finally the laboratory testing results in terms of petrographic, chemical as well as variable volumetric values have to agree with the site investigation results and observations:

Influence of water uptake and binding by frost-thaw action with respect to clay slope movements.

The first year of research has been devoted primarily to the material - the swelling freshwater clay - identification. First the mineralogical composition, the bulk chemistry, the possibly influencing physical parameters like grain size distribution, plasticity, the capability for water adsorption, and vane shear strength etc. Of course first laboratory testing of dilatometric behaviour during water adsorption and qualitative-phenomenological behaviour during freezing and thawing. The field observation equipment like thermometers soil strain gages, piezometers, has been installed. First field data are to be expected in the second year of the study.

Fig. 1 shows the flow chart of clay identification. Under "Clay minerals" the preparation methods for x-ray diffraction are listed. ADPO = air dried preferred oriented; EG = ethylene glycole; 550° = burning temperature of ADPO mount; DMSO = dimethylsulfoxide.

Fig. 2 contains the test site measuring devices currently under operation. They have been installed in November 1983, therefore test results are to be expected in the following research period.

2. General Geology of Study Area

The test site is located within the alpine Freshwater Molasse of the Hausruck area belonging to the province of Upper Austria (See fig. 3). Slope movements in the area are known for decades.

The clays are rich in montmorillonite, belong to a fluvial - fresh water cycle and are possibly influenced by volcanic ash falls. The series under investigation belongs to the upper Miocene of the Tertiary (Badenian, according to the paratethys classification). The local stratigraphic classification calls it "coalbearing fresh water series" with a thickness up to 100 m. The top strata, overlaying the coalbearing series, are made up

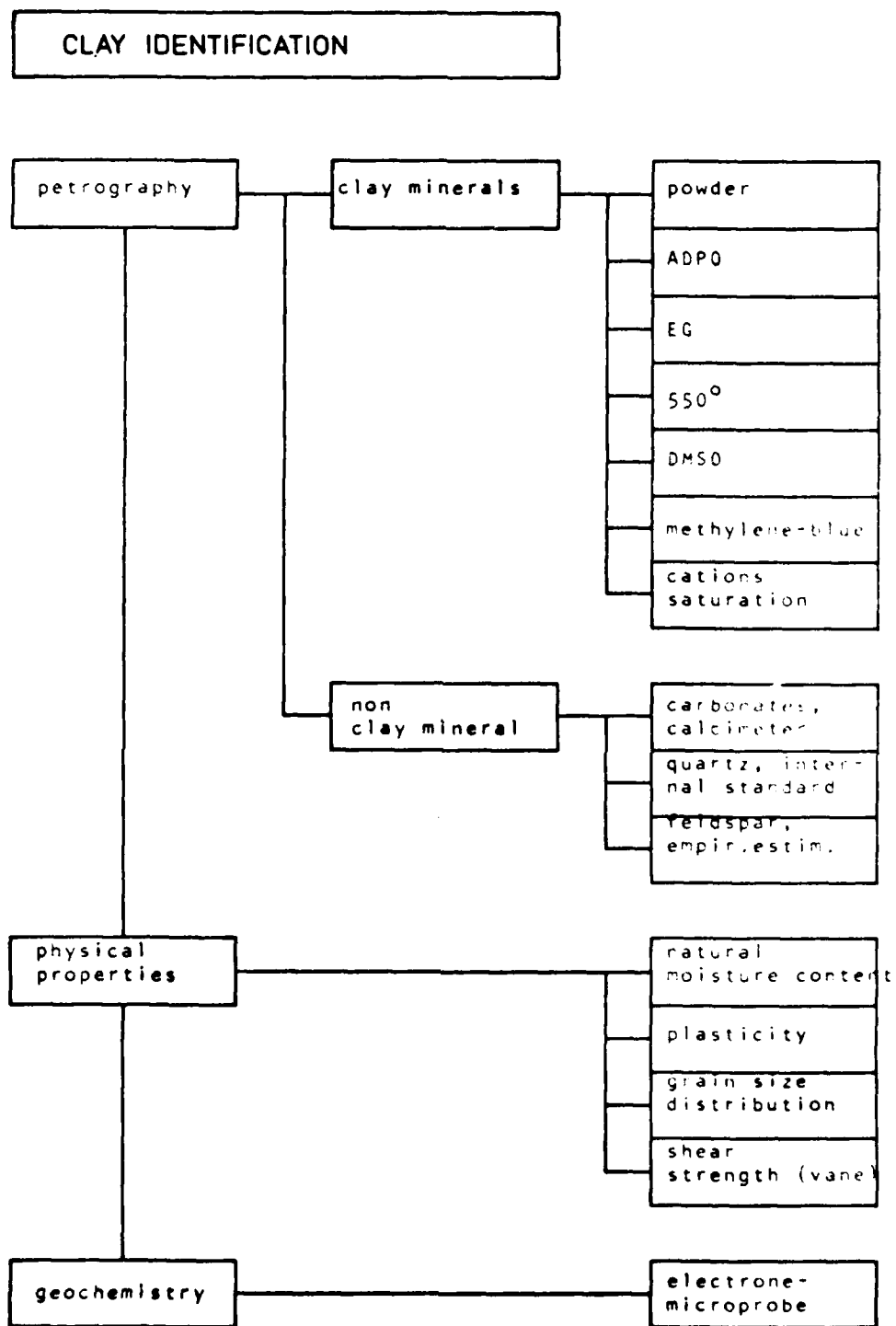


Fig. 1: flow chart of clay identification methods, performed on the freshwater clay of the test site in Renigen, Upper Austria

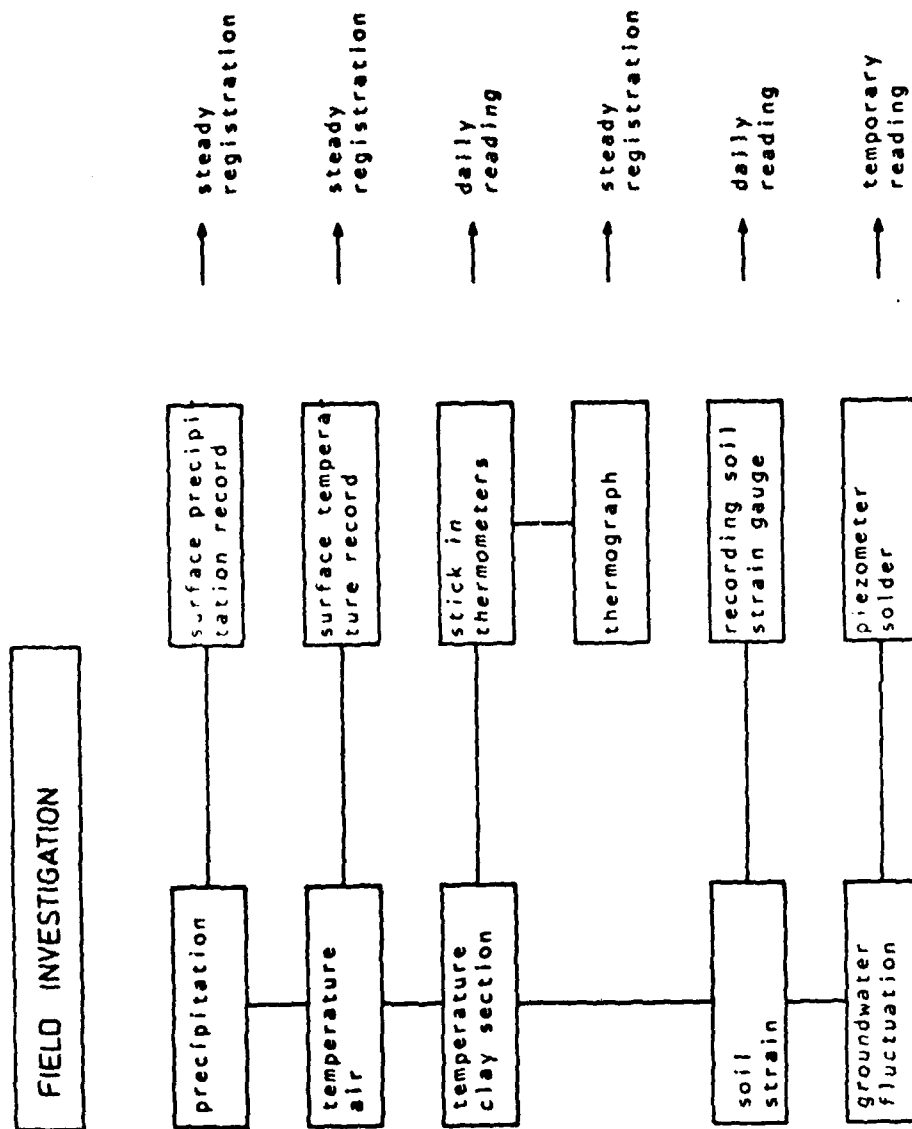


Fig. 2: flow chart of field investigation methods, currently operating at the test site in Renigen, Upper Austria

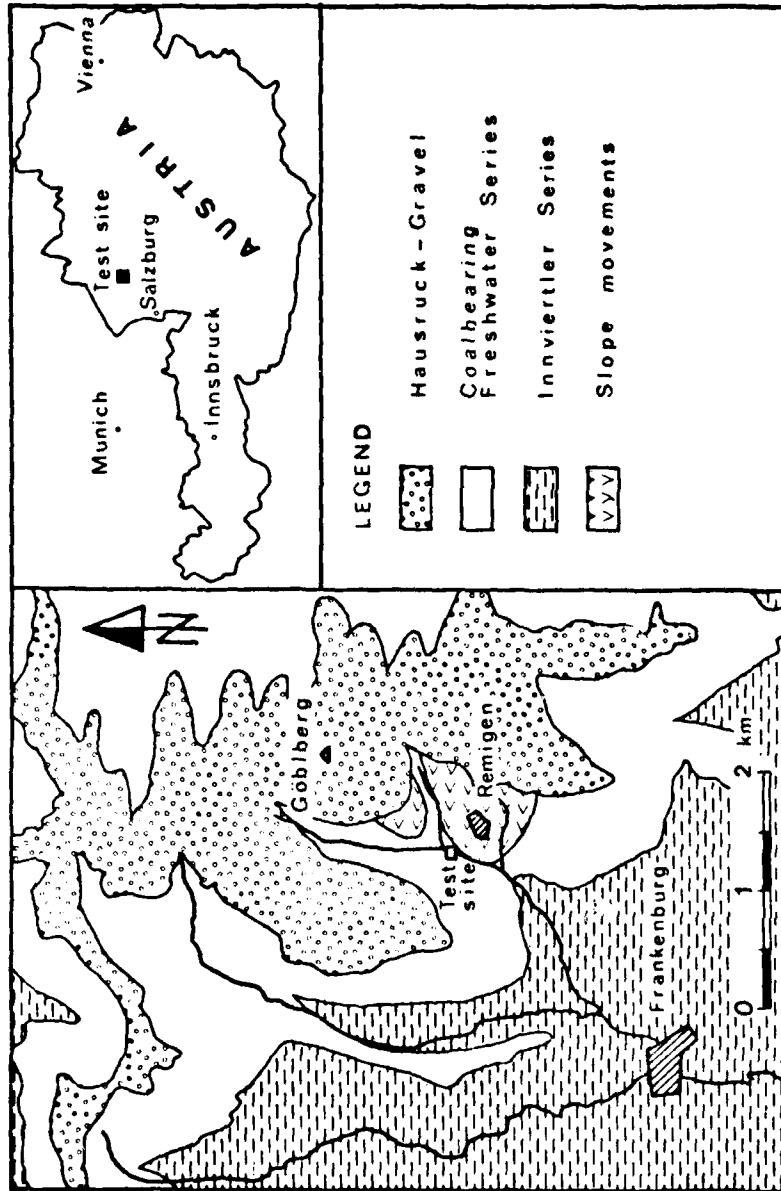


Fig. 3: Situation of investigated area, geological sketch map.

of a fluviatile conglomerate resp. loose gravel, called the "Hausruck Schotter" (See fig. 4).

The coal of the Hausruck area occurs in three seams. Usually only the lower most seam is worked. There are mining activities near the creeping area and the test site.

3. The Soil Creep Event

Beginning with spring 1979 in Frankenburg-Renigen on a W dipping gentle slope distinct mass creep phenomena could be observed. Pretty soon almost all of the farm buildings showed cracks. They have widened steadily and in the mean time two farmhouses at the toe of the creep mass had to be evacuated. The test site is located immediately in front of the slide toe region near one of the farmhouse ruins. The creep obviously goes on and neighbouring parts of the slope are now affected too.

The main scarp of the sliding mass is to be seen in the uphill area where mining already has caused considerable failures and settlements. The failure surface of the Renigen-Ottigen land creep has the typical S-shape with the steep scarp on top - with tension cracks and small tension valleys resp. forming series of steps - while the toe of the slope (Schnöllhof-brook) bulges upward. The sliding plane is to be expected in the shape of a characteristic logarithmic spiral.

4. Results of Clay Identification

4.1. Rock Physical Properties

The samples choosen for the freezing tests are fresh water clays of high plasticity with little organic (coal) components and sporadically a few calcite concretions (Ø a few mm) and quartz pebbles occur.

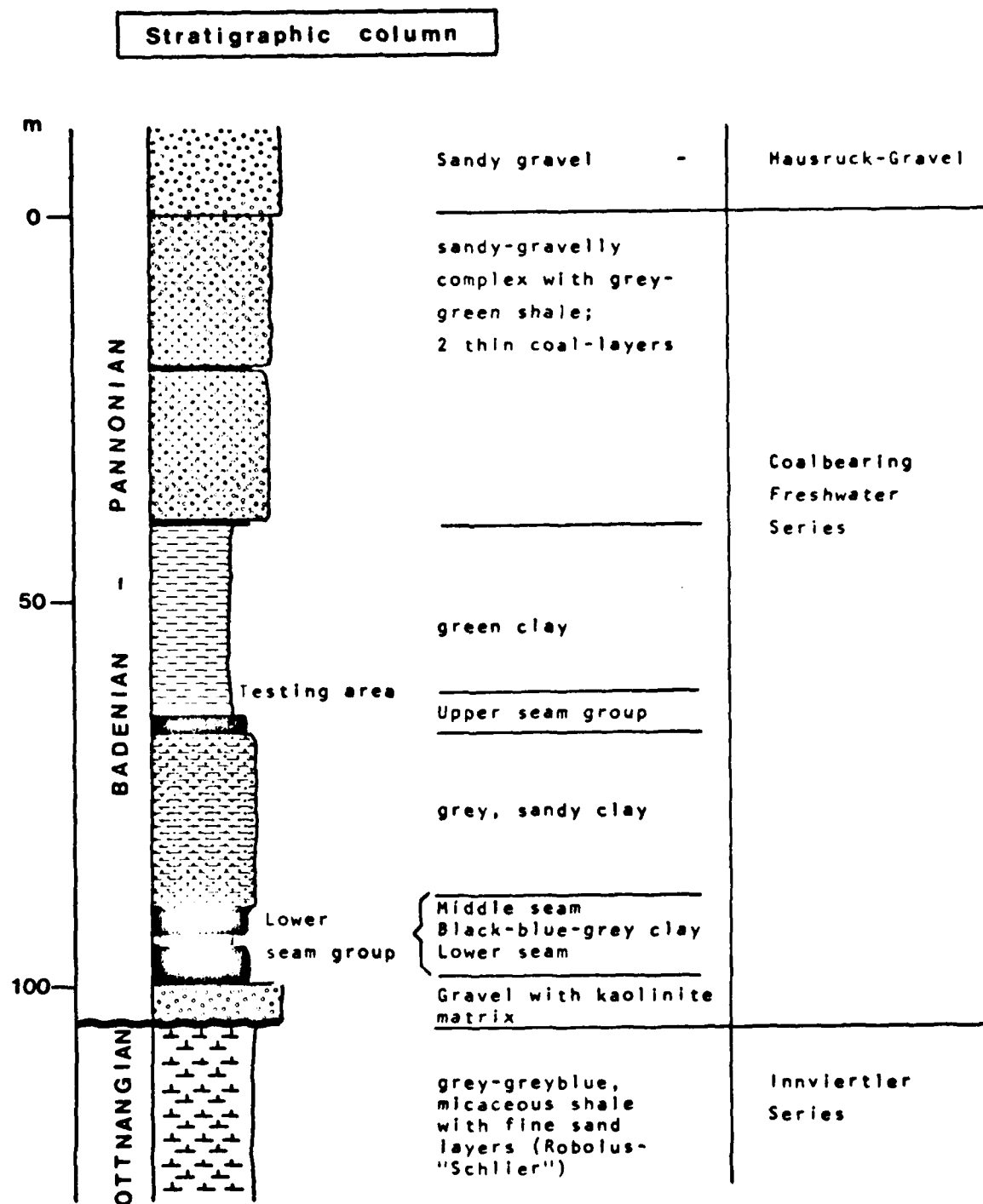


Fig. 4: Stratigraphic column of the Upper Freshwater Molasse (Miocene) for the investigated area. (according to ABERER, 1958)

4.1.1. Plasticity Indices

A great number of Casagrande liquid limit - and plastic limit tests were performed. The test results give the i_p - area (plasticity index) within the plasticity chart of fig. 5: i_p between 16 and 35% and the liquid limit w_L between 42 and 65%; indicating a plastic clay to plastic silt clay. The natural water content w and the plastic limit w_p lies between 26 and 30%. The consistency index $I_c = w_L - \frac{w}{I_p} = 0,97 - 1,0$; this means that the consistency of the natural investigated clay is solid to semisolid. The plasticity is determined by the amount of clay size particles: up to 70% and the amount of montmorillonite: up to 35%.

4.1.2. Grain Size Distribution

Twelve hydrometer tests were performed, resulting in twelve grain size distribution curves. They cover the distribution field shown in fig. 6. The critical content in clay size particles - which are composed solely of clay minerals - reaches from 35 to 70%, which is a comparatively wide range. This is one fact for the up to now scarcely to generalize swell and freeze behaviour.

4.1.3. Sliding Parameters

For a first shear strength determination in the laboratory, with measurements near the surface of the samples, a small portable vane tester was used. The unit allows instant accurate determination of clay shear strength to be made. A vane of 19 mm diameter was used for all tests. The pointer was rotated clockwise at a speed equivalent to a complete revolution in a minute. When the sample has sheared, the pointer remains set and enables a reading of shear strength determined from the scale corresponding to the vane used. A further rotation gives the value for the residual strength.

The shear strength, a main parameter in evaluating sliding resistance, depends strongly on the water content - besides other parameters like grain size distribution, mineralogical composition, fabric, slope inclination etc. The diagram of fig. 7

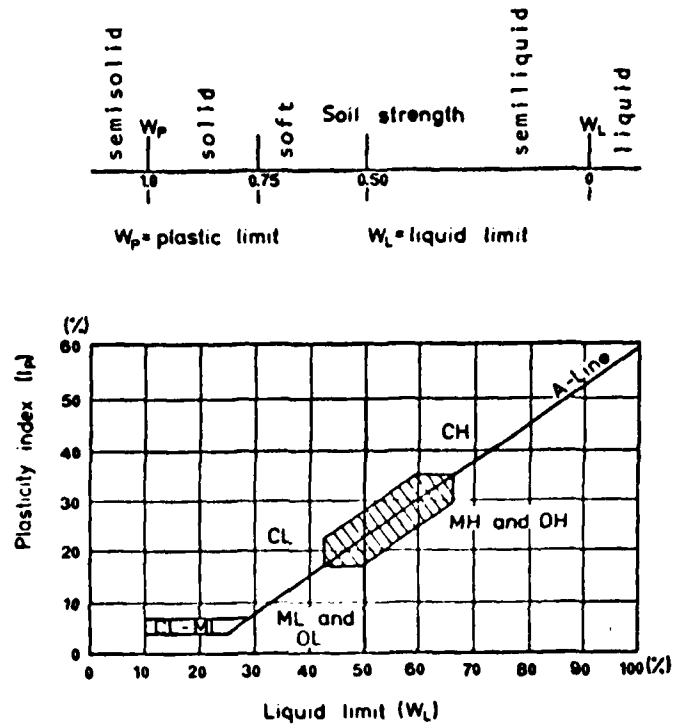


Fig. 5: Field of plasticity indices of investigated freshwater clay (high montmorillonite content) within Casagrande plasticity chart for the classification of fine-grained soils. (CL = low plasticity clays; ML = silts, very fine sands, clayey fine sands; OL = organic silts and clays of low plasticity; MH = micaceous silts; OH = organic silts and clays of high plasticity; CH = highly plastic clays)

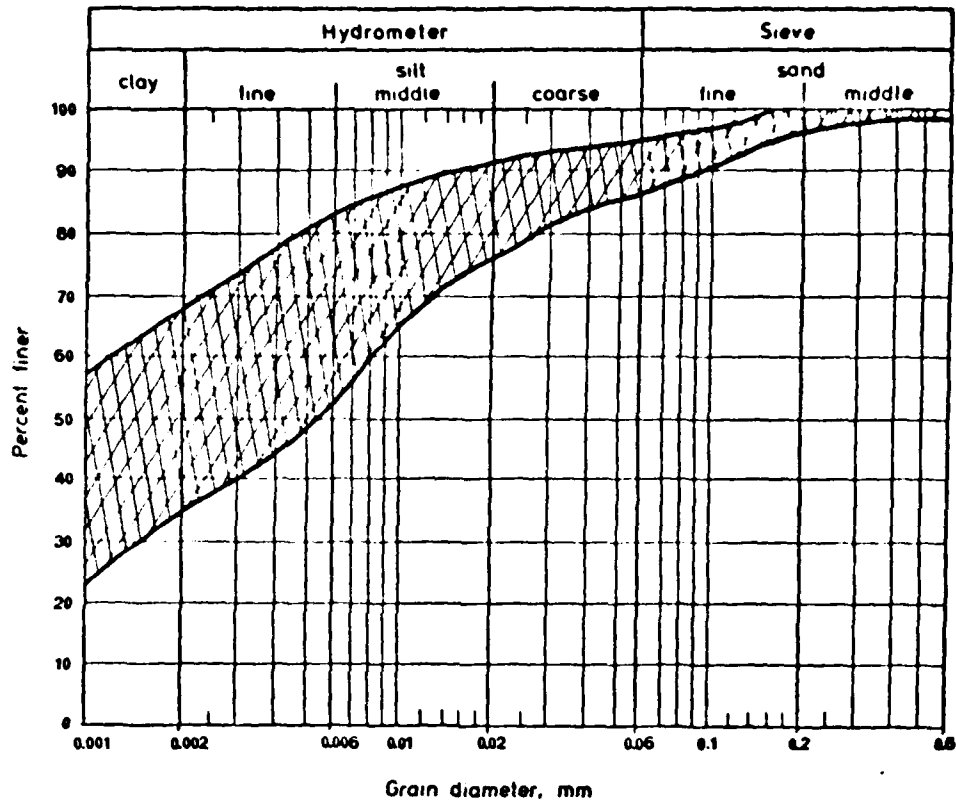


Fig. 6: Field of grain size distribution of investigated freshwater clay in semilogarithmic plot. Content of clay size particles up to 70%.

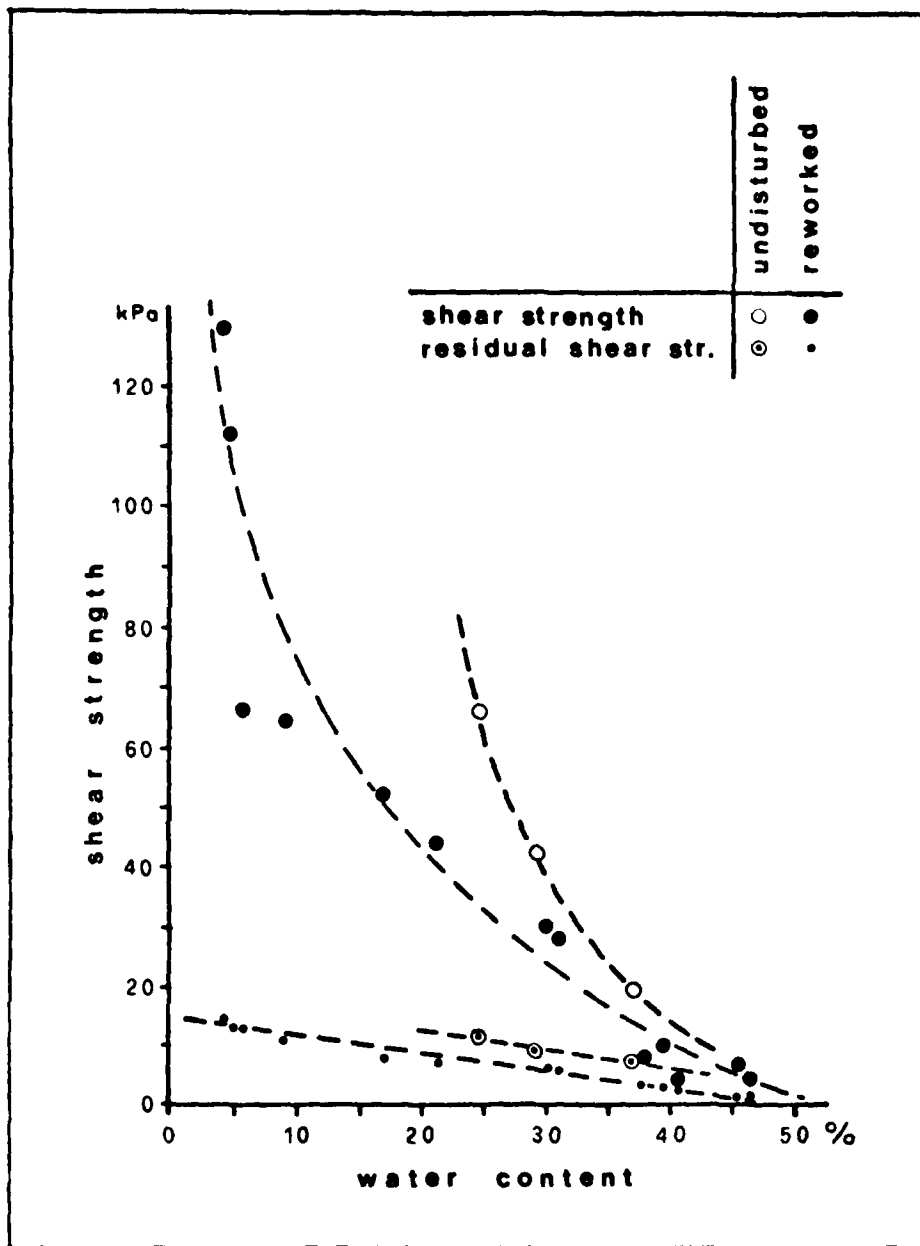


Fig. 7: vane shear diagram. Shear strength and residual strength. Dependence of shear strength from moisture content and original fabric (undisturbed samples with higher shear resistance).

shows the dependence very distinct: between 50 kPa at 15% water content and 5 kPa at 47% water content. The maximum shear strength values for almost desiccated samples (w below 10%) are not reliable because of sample disturbance by inserting the vane.

Natural (original) fabric conditions give the clay a much higher shear resistance compared with remolded clays. Freezing and swelling means remolding and therefore considerable weakening of the clay affected. The higher the moisture content, the lower the shear strength differences of original and remolded clay samples.

4.2. Semiquantitative Petrography

4.2.1. Identification Methods

The clay samples in question have been taken partly by hand and partly by machine drillings and by digging out of a trench. The samples, taken at different depths, were analyzed semiquantitatively.

For the determination of quartz and feldspars x-ray powder analyses were performed. Philips diffractometer, machine settings: Cu K α - radiation, Ni-filter for elimination of K β - radiation. X-ray generator: voltage 40 KV, current 20 mA; goniometer speed: 1° = 20/minute; recorder: range 4×10^2 , time constant 8; paper speed: 600 mm/h.

The total carbonate content was measured by means of the Scheibler-calculator, a gasometric CO₂ - determination. The percentage of calcite and dolomite is calculated from the corresponding peak intensities of x-ray traces and corrected by the mass absorption coefficient.

The quartz-content could be calculated by using an internal Boehmite-standard. (Boehmite = AlO (OH))

The clay mineral content, especially the different clay phases, are semiquantitatively estimated from x-ray traces by allowing

for different, mineral specific, correcting factors. The x-ray traces were gained from air dried, preferred oriented samples. In order to separate superimposed peaks, different preparing methods had to be used: ethylene glycol saturation, saturation with dimethylsulfoxide, burning at 490°C (See fig, 8). The swelling clays are determined quantitatively by measuring the methyleneblue absorption into the interlayer space of the swelling phases. ("Halo" - methode). The dimethylsulfoxide-method (DMSO-method) proofs the occurrence of kaolinite if chlorite is present too. The 7 Å kaolinite peak shifts towards the 11 Å space (fig. 9).

4.2.2. Petrography

The clay with the highest montmorillonite content (presumably weathered volcanic ashes) was found in the middle part of the Coalbearing Freshwater Series, forming the toe of a landcreep mass.

According to the results gained by the above (chapter 4.2.1.) mentioned methods the following mean mineral composition (value of deviation from 15 samples) can be stated:

quartz 9% (6 - 20%)	illite-muscovite 42% (35-48%)
feldspar 3% (1,5 - 5%)	chlorite 14% (6-21%)
calcite 6,5% (1 - 15%)	kaolinite 2% (1- 5%)
dolomite 0,5% (0 - 4%)	montmorillonite 23% (15-35%)
Non clay phases 19% (15-30%)	Clay phases 81% (70-85%)

Table 1: mean mineral/composition of freshwater clays from test site Renigen: Coalbearing Freshwater Series.
Data base: 15 analyses.

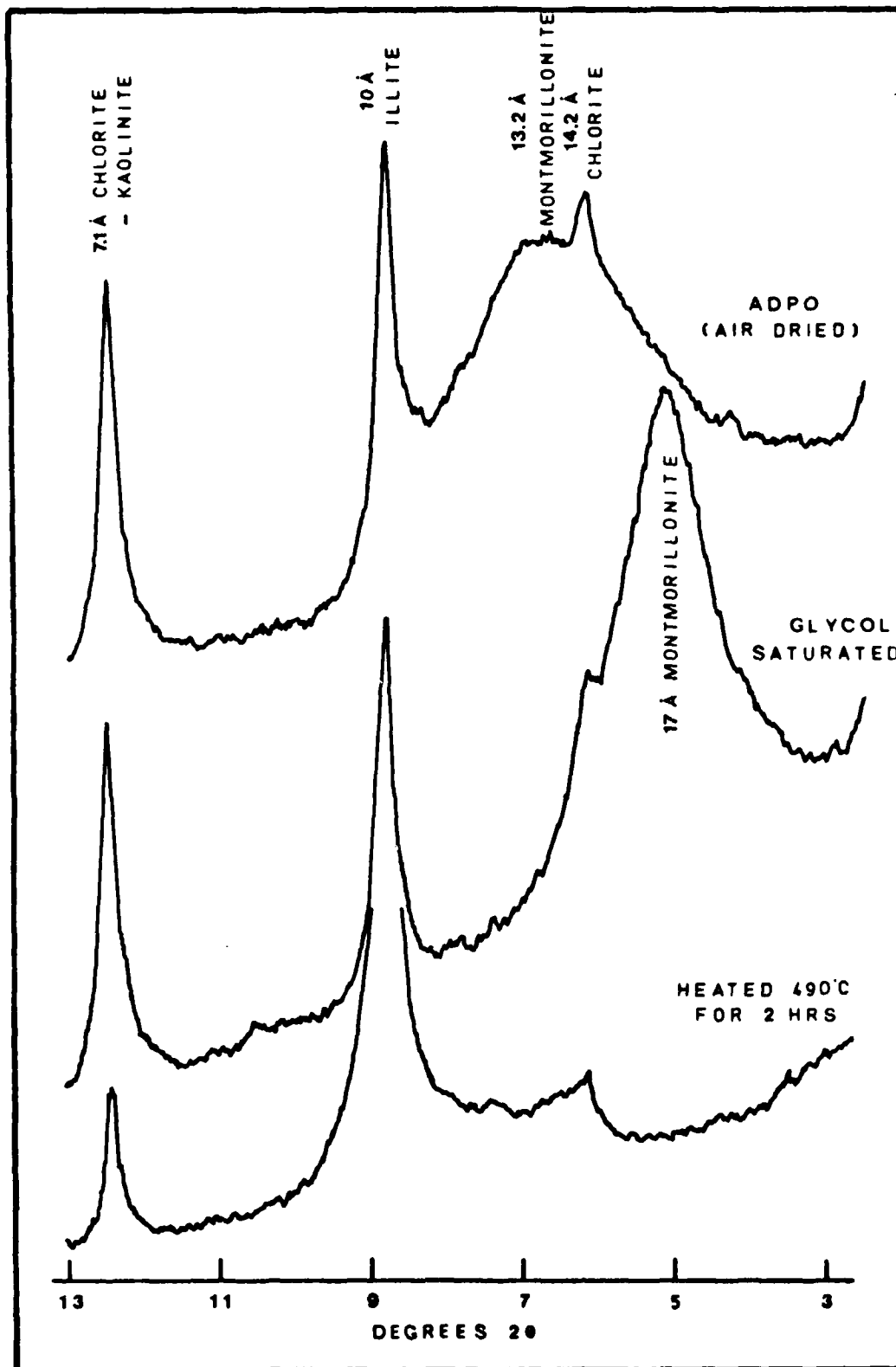


Fig. 8: xRD-traces after different preparation methods. From Coal-bearing Freshwater series. ADPO=air dried preferred oriented.

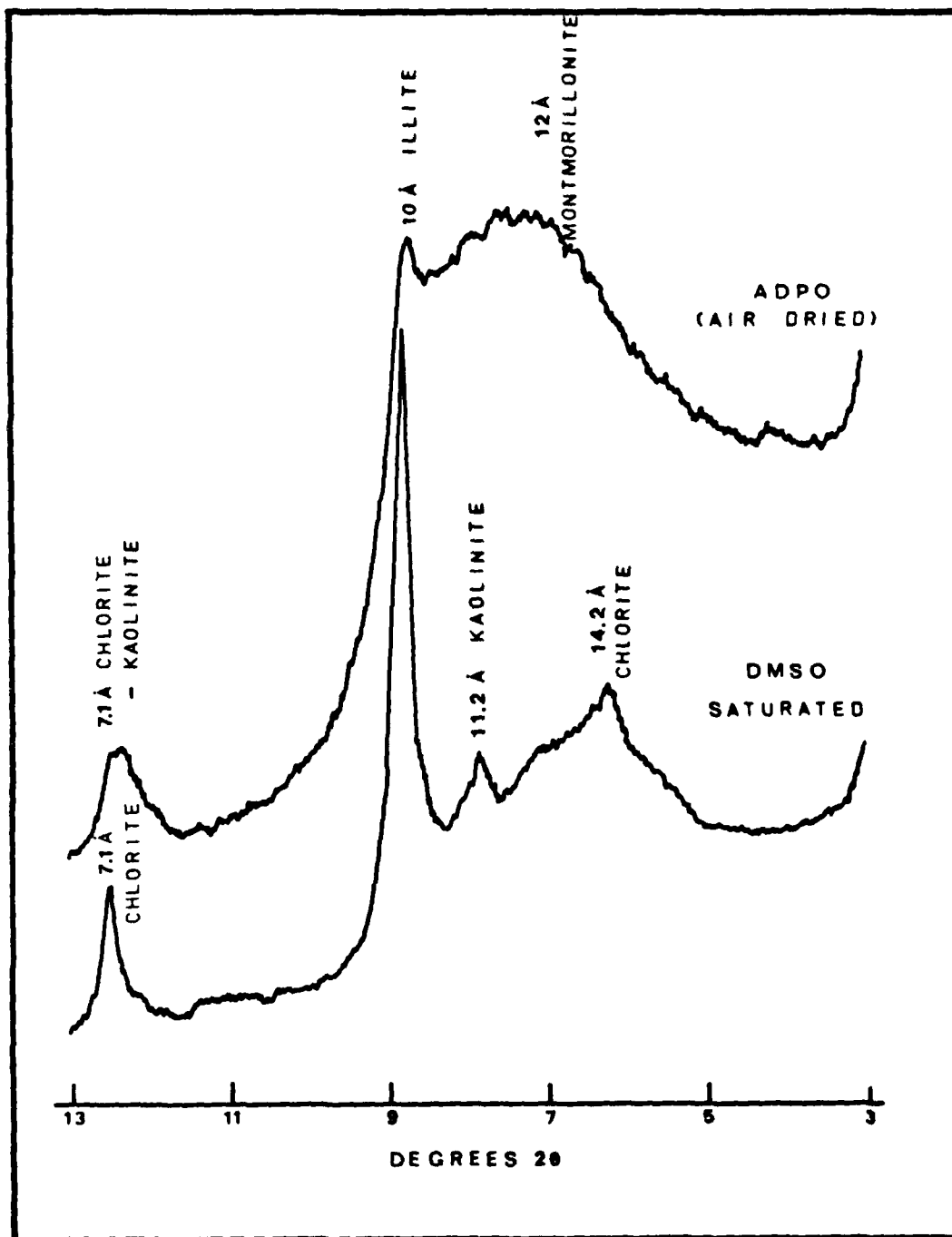


Fig. 9: x-ray traces for distinction of chlorite from kaolinite by DMSO (Dimethylsulfoxide) - saturation. ADPO = air dried preferred oriented. Clay from Coalbearing Freshwater series.

The comparatively wide range in the percentage of the different mineral phases from a small sampling area of only a few m^2 and not more than 2 m depth gives a hint for explaining different swelling behaviour. This has still to be checked and quantitatively evaluated.

Fig. 10 shows a semiquantitative plot of mineralogical composition of six samples from test site drilling section within the "Coalbearing Freshwater Series".

4.3. Bulk Chemistry and Interlayer Cations

The bulk chemistry and kind of adsorbed interlayer cations has been determined for several clay samples (Tab. 2 and 3). The exchangeable cations have been treated with NH_4 CNS-solution thus sorbing these molecules, and replacing the original cations which are now concentrated in the supernatant solution. The final CEC-determination was determined by re-saturation of the clay with Na Cl, the cations measured by an atomic adsorption spectrometer (AAS). As Ca^{++} is the principal extracted interlayer cation, it is supposed that the chemistry of our montmorillonite is that of a Ca-montmorillonite, what could also be deduced from the bulk chemical analysis. Nevertheless some leaching out of the materials carbonate content may free and readSORBE Ca-ions.

Further investigations shall try to separate this montmorillonite from the other clay minerals, so that a more adequate analysis of its chemistry and of its cation exchange behaviour may be realized. This will be very important for the following freezing tests with different saline solutions.

5. Swell Behaviour

5.1. Test Methods

A swell heave apparatus was constructed where 4 samples at a time can be tested and registered by means of dial gauges. Water penetrates through a filter stone from the bottom by means of a falling head device. In order to induce slight overpressure,

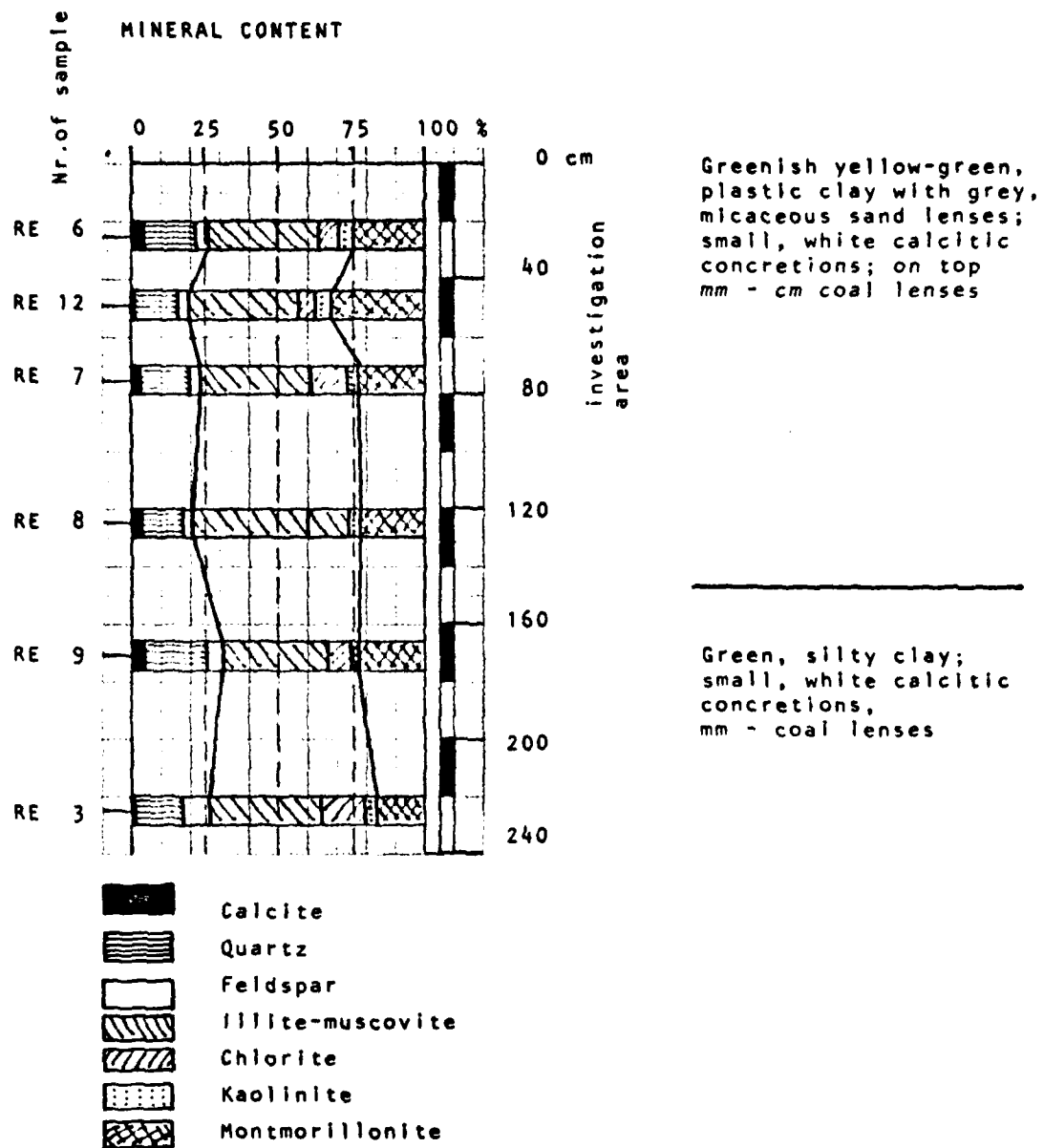


Fig. 10: Mineral content of a drilling section at the Investigation site Renigen; Coal Bearing Freshwater Series

Chemical composition (%)	RE 9	RE 11/2	RE 12
SiO ₂	61,26	45,97	61,07
TiO ₂	0,75	0,71	0,61
Al ₂ O ₃	17,20	19,43	18,17
Fe ₂ O ₃	6,05	6,43	6,20
FeO			
MnO	0,12	0,28	0,10
MgO	1,80	0,84	1,63
CaO	2,76	9,62	1,63
Na ₂ O	0,29	0,30	0,34
K ₂ O	2,88	3,37	3,59
P ₂ O ₅	0,09	0,19	0,08
Heat loss	6,81	12,86	6,59
total	100,01	100.--	100,01

Tab. 2: chemical analyses of three clay samples from test site Remigen. Bulk chemistry by microprobe measurement on rock melts.

	RE 6	RE 7	RE 8	RE 12
CEC (meq/100g), total	79,0	73,0	47,0	86,0
exchangeable cations				
Na ⁺	0,3	0,3	0,3	0,5
K ⁺	1,0	0,5	0,8	0,8
Ca ⁺⁺	44,0	60,0	50,0	70,0
Mg ⁺⁺	6,4	6,6	5,2	5,4
Total (meq/100g) of main interlayer cations	51,7	67,4	56,3	76,7

Tab. 3: cation exchange capacity (CEC) and main interlayer cations of four clay samples from test site Remigen.

the water table in the falling head burette was kept slightly above the filter stone table. The clay specimen of 50 mm diameter and 50 to 60 mm length were mounted in closely fitting plexiglass cylinders which allowed uni-axial swelling only and steady water uptake through a tube shaped bottom part, connected with the burette mentioned by means of a tube.

A second type of swell test was performed by means of an Heraeus dilatometer. In the dilatometer, the change in length or volume of a sample (size: 8 mm diameter, 10 to 50 mm length) causes a shift of the probe. This shift is converted into a D.C. voltage by a linearly variable differential transformer. This transformer permits a resolution of 0,1 μ m of probe shift per centimeter of recorder deflection. In order to make use of the high accuracy of the dilatometer, it is necessary to thermostate the dilatometer head, because a change in temperature of 1°C would simulate a change in length of 2 μ m.

5.2. Swell Behaviour

The tests discussed in this chapter were performed by the self designed swell heave apparatus and the Heraeus dilatometer. Despite the different sample sizes, the results are comparable and are plotted in the same diagrams. This because of the same test principle: undisturbed samples with bedding planes vertical to swell heave direction, confined by sample tubes and moisture uptake by bottom adhesion from falling head device resp. in the case of the dilatometer solely by water adhesion.

As can be seen clearly from the diagrams in fig. 11, the extent of swell heave depends on the amount of moisture uptake and in return this depends on the initial water content.

The dependence for swell heave and initial water content out of 75 swell tests can be stated as followed:

Swell heave of 5 to 15% for initial water content of 0%
(105°C over dried)



Fig. 11: Semilogarithmic plot of time dependent water uptake respectively swell heave of samples with different initial water content. Swell heave absolute in mm and in percent of length specimen. Laboratory testing results of undisturbed freshwater clay samples.

Swell heave of 3 to 8,5% for initial water content of 14%
(air dried)

Swell heave of 1 - 3,5% for initial water content of
22-28% (natural moisture content)

The wide range of the heave rates can, in essence, be referred to the different montmorillonite contents (see chapter 4.2.2.)

The montmorillonite content amounts to only 22% for the sample shown in fig. 11. Swell heave increases parallel with the amount of expanding clay minerals.

Swell heave goes on until water saturation, that ranges between 28 and 34%, is attained.

Swell pressures for 3 samples were also measured. Two samples with low montmorillonite content (16 resp. 19%) show pressures of 40 resp. 60 KN/m². A sample with high montmorillonite content (34%) a pressure of 90 KN/m².

Very dry clays with almost zero moisture content indicate danger for constructions for they show a swell heave up to 15%. On the other hand, a water content of about 30% - as it is the case with the original samples - indicates, that most of the expansion has already taken place and further expansion will not occur. Time dependent it can be stated, that the swell heave goes steadily but increases tremendously if water pressure is risen. Shifted towards field conditions, this means considerable swell heave of the ground surface parallel to possible rises of the groundwater table. However, moist clays may desiccate due to lowering of the water table or other changes in physical conditions and exhibit swelling again upon subsequent wetting.

6. Freeze-Thaw-Behaviour

6.1. Freeze Box

For gaining first data on the freezing behaviour of the investigating montmorillonitic clay, a cold box was constructed. (fig.12)

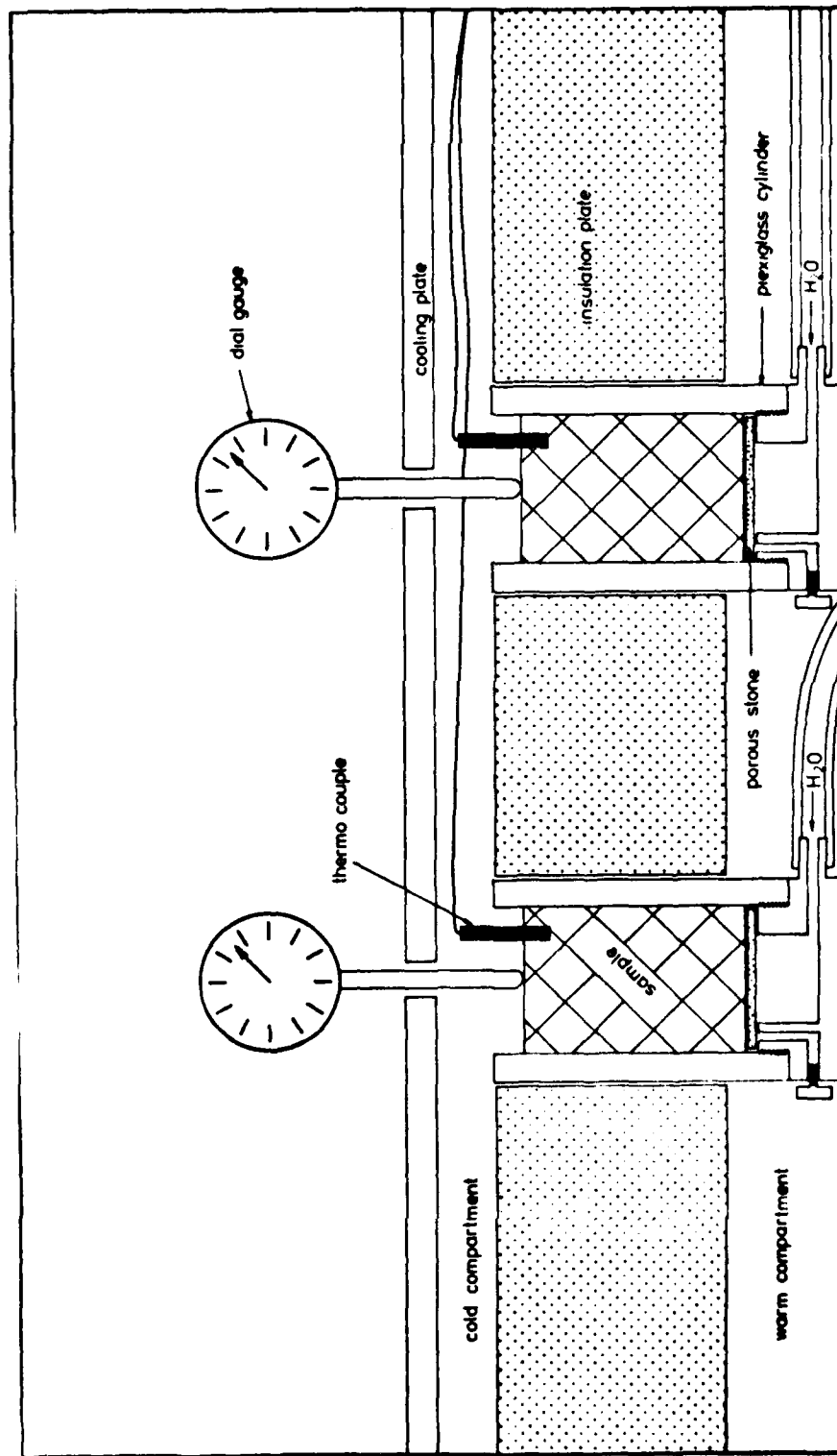


Fig. 12: schematic sketch of freeze box

A freezer, divided by an insulation plate in two compartments, simulates natural freezing conditions. In the upper part, the cold compartment, the temperature can be lowered to -32°C . In the lower part, the warm compartment, the temperature is moderately tempered above the freezing point so that ground water temperature is nearly simulated.

Orientated taken clay samples from the freshwater clay at the test site were used for the experiment. Free movement of the sample during freezing was made possible by setting the sample into a greased plexiglass tube. Water could be adsorbed through a porous stone. The plexiglass cylinders enable the same sample dimensions as those for the swell tests (chapter 5.1.), so that the samples may be installed after freezing in the swell heave apparatus, where the thaw-behaviour can be observed and a new swell test, only by water uptake, may be performed.

6.2. Freeze-Thaw-Behaviour

For the freezing tests performed the temperature was varied in the cold compartment between -14 and -30°C . The temperature in the warm compartment was held between $+1$ und $+4^{\circ}\text{C}$ so that the frost front in the sample could penetrate as low as possible. In general it could be observed that the clay sample only freezes, when the sample temperature falls below -4°C .

Several non-water saturated samples were frozen without the possibility of water uptake; they have shown no ice swelling at all.

As well 8 water-saturated samples were frozen in the same manner. They showed ice swelling rates between 2,2 and 5,5%.

Freezing of clay samples with simultaneous water adsorption proceeds very slowly. It takes several weeks until ice swelling stops. Up to now 9 representative freezing tests with water uptake were performed. The amount of ice swelling ranges between 29 and 52% of the frozen part. In general, oven dried samples,

Installed in the freezer, show first a swell heave of about 7% (mainly swell heave, unknown part of ice swelling) until water saturation and a subsequent ice heave of about 40%. (fig.12a)

From this we can suppose that by freezing with simultaneous water adsorption first a maximum interlayer swell heave will be attained, followed gradually by ice heave according to increasing penetration of the frost front and in addition to increasing water content. On thawing a rapid shrinkage starts immediately, passing the initial volume and finally levelling out at a volume decreased by approximately 3%. On water saturation again a swelling process enables expansion up to the swell heave volume level. (see fig. 13).

7. Field Investigations

In order to gain first data on the in situ behaviour of the swelling clay during a frost period, a first set of heave-, temperature- and groundwater fluctuation registration units have been installed at the test site Renigen beginning of November 1983. (see fig. 14).

It is the main task to gain data from an undisturbed clay section. Therefore a pit of 2 x 1 x 1,2 m was digged and after the installation of the measuring equipment within an undisturbed wall, filled up again by the before digged out clay. The undisturbed clay wall contains now the following instrumentation: 8 soil strain sensors, 3 temperature probes and 5 stick in thermometers. In addition, piezometer observation is done periodically in a 5,6 m borehole near the measuring station. Precipitation and air temperature registration is done in the village of Frankenburg near the research station.

7.1. Soil Strain Measurement

The soil strain gage detects and measures the extent of swelling and shrinkage accompanying moisture and temperature change.

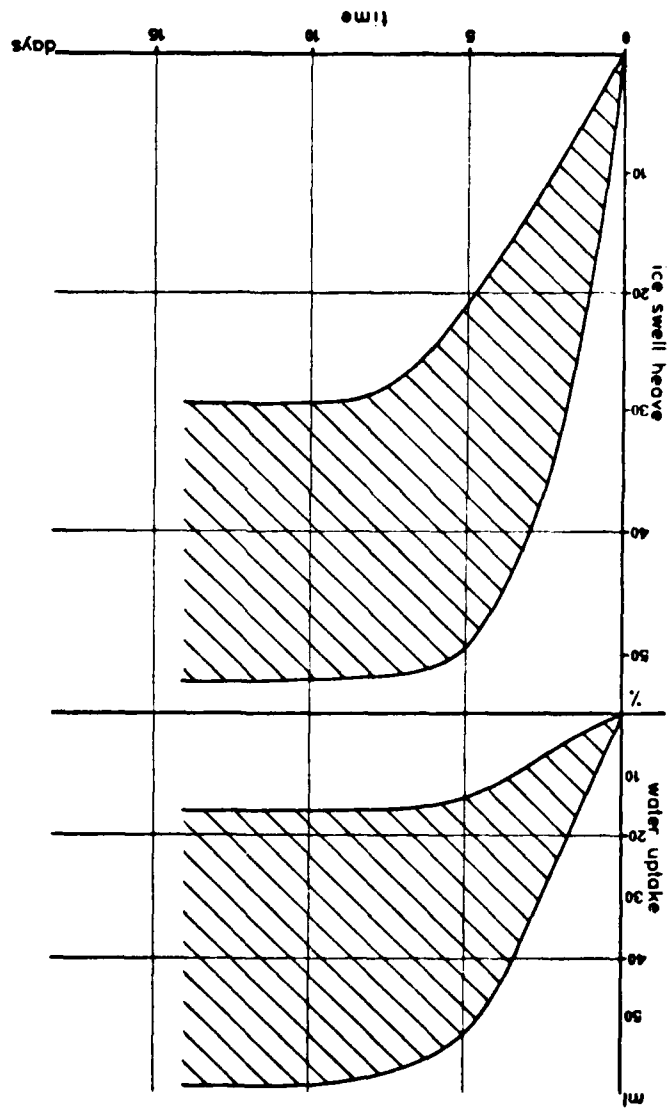


Fig. 12a: ice- and water swell heave and amount of water uptake time dependent

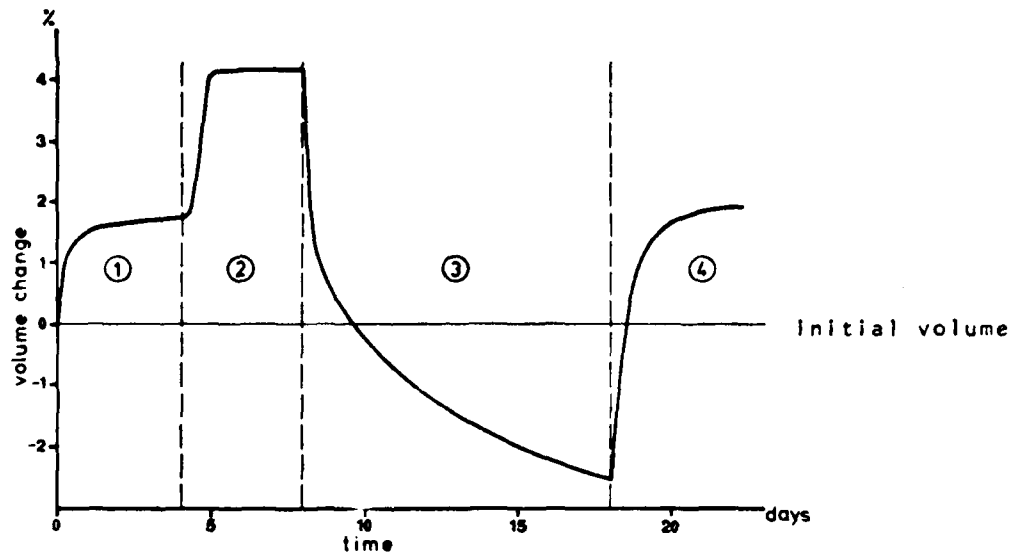


Fig. 13: ① Swell heave of a clay sample with natural water content
② Ice swelling of the water saturated sample without water uptake
③ Thawing and shrinking
④ 2nd swell heave until water saturation
ice- and water swell heave and thawing diagram;
volume change time dependent

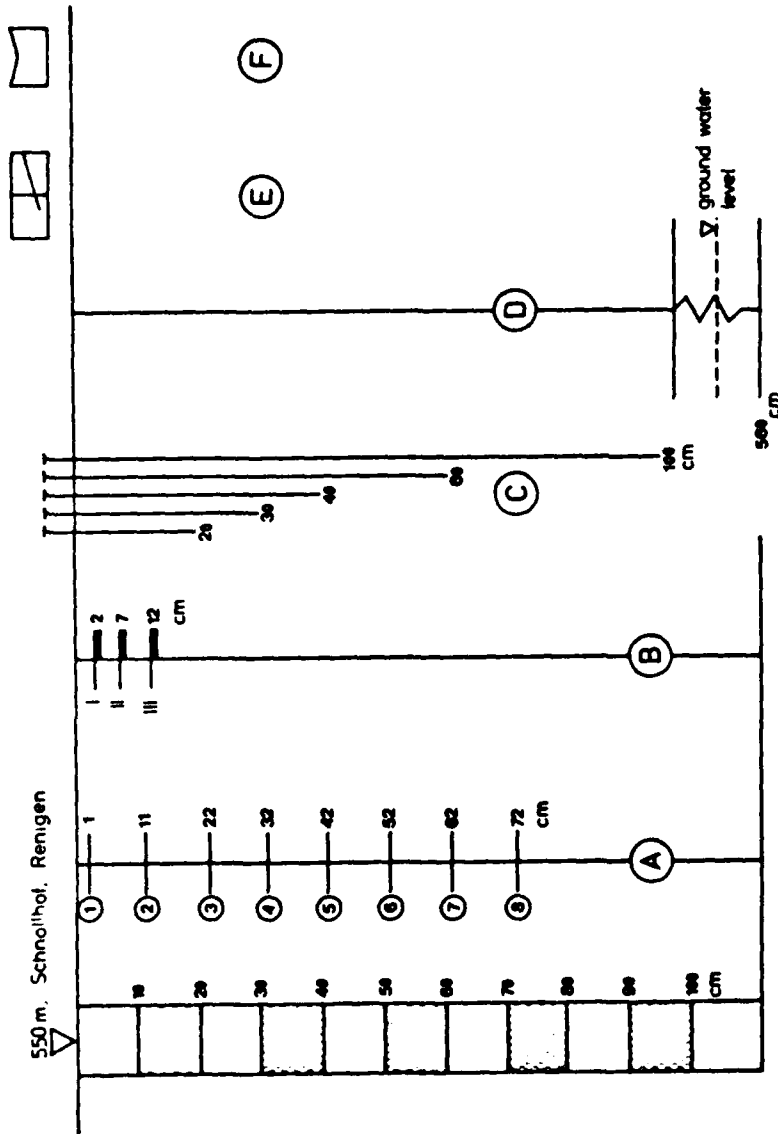


Fig. 14: A soil strain sensors
 B Thermoprobes
 C stick in thermometers
 D piezometer borehole
 E air temperature recording
 F precipitation recording
 system sketch of test site measuring equipment

The essential elements of the soil strain gage are 1. pairs of rugged disk-shaped sensors embedded in the soil in near parallel and coaxial orientation separated by a distance over which the strain is to be averaged and 2. a portable instrument package to which the sensors are connected, including all necessary driving, amplification, balancing, recording and calibration controls and self-contained power supply.

The accuracy of the readings is not affected by changes in soil composition or moisture content. Changes in temperature have negligible influence on readings.

Changes in spacing (extension or compression) of a pair of sensors are monitored very accurately by means of changing the magnetic field around the sensors. Sensor dimensions operating at the test clay section: diameter 5,1 cm, thickness 0,125 cm. A strain as small as 0,01% may be registered.

For now readings are done twice a day in order to cover the night and day variation during the freezing period. The initial sensor distances are 10 cm for each pair of the eight currently installed coils. Our measurements reach down to 70 cm for we do not expect any strains deeper than this.

7.2. Temperature Recording

Beside the steady air temperature and precipitation monitoring at the meteorological station Frankenburg, near the test site, subsurface temperature measurements are performed within the clay section under investigation. For this purpose three thermoprobes connected with a steady registration drum are installed at 2, 7 and 12 cm depth. They serve the purpose to detect the frost penetration depth. Five more thermometers with dialplate readings are stucked into the ground measuring ground temperature changes at 20, 30, 40, 60 and 100 cm. Frost penetration is expected not deeper than 30 cm.

The thermometers have been installed already in spring 1983. The periodical readings showed the following depth dependent temperatures:

Tab. 4: thermometer readings, Renigen test section

depth of measuring point	April	May	August	November	
	8.4.	10.5.	2.9.	3.11.	7.11
100 cm	8°C	10°C	13°C	10,5	9
60	6	8	13	8	7,5
40	6	8	13	7	6,5
30	5	8	13	6	6
20	5	9	14	6°C	5°C

7.3. Piezometer Readings

A 5.6 borehole enables measurements of the groundwater level and the water temperature. In April 83 (immediately after drilling the hole) the water level could be detected at 4,20 m below ground surface ($t = 6,5^{\circ}\text{C}$) and in November at 2,25 m at $t = 9,4^{\circ}\text{C}$.

8. Research Plans for the 2nd contract year

The just finished 1st research year has gained a good knowledge of the material we are dealing with: petrography, geochemistry and soil physical properties of a freshwater clay. First laboratory test data on swell- and frost behaviour could be gained but almost no field data up to now. Laboratory and field installations took some time.

The coming year will increase the data base in laboratory and especially in field testing. This winter, unfortunately up to now extremely mild in Austria, and the coming winter 1984/85 (which is the last one within the contract period) have to prove in situ swell and shrinkage behaviour at the test site. Soil strain gages, temperature probes, a piezometer and a meteorological station is installed and currently operating. A porewater pressure probe might be the last site installation within the coming year.

In the lab much more freezing-, thawing- and swelling data will be gained from dilatometric-, microprobe and x-ray diffraction for we assume strong dependencies of swell behaviour not only from mineralogical and geotechnical parameters but from environment caused microstructural features as well.



Fig. 15b: test site Renigen; soil strain gauges and temperature probes in undisturbed section



Fig. 15a: test site Renigen; clay pit without measuring instrumentation

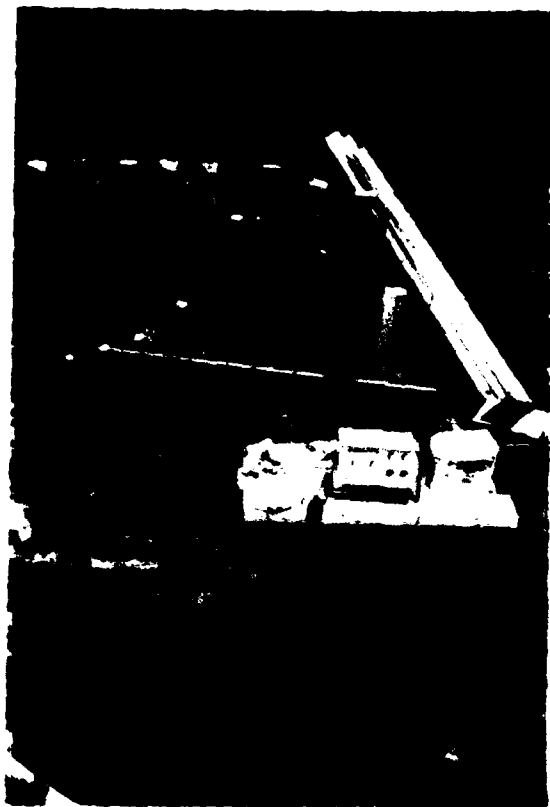


Fig. 16a: test site Renigen;
soil strain and
temperature gauges
with monitoring
equipment



Fig. 16b: test site Renigen after installation of
measuring equipment and closing of
installation pit

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